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(54) Title: OPTICAL FIBER FOR LIGHT AMPLIFIER

(57) Abstract

An optical fiber used for an optical amplifier, which is formed by doping glass with rare-earth ions. Both prasecodymium ions (Pr^{+3}) and erbium ions (Er^{+3}) are used as the rare-earth ions, and the glass is a fluoride glass or a sulfide glass. The optical fiber can be used at both wavelengths of 1.3 μm and 1.55 μm. The light amplification efficiency of an optical amplifier made of the optical fiber can be improved compared to an optical amplifier formed of only Pr^{+3} or only Er^{+3}.

OPTICAL FIBER FOR LIGHT AMPLIFIER

Technical Field

The present invention relates to optical fibers for use in a light amplifier, and more particularly, to an optical fiber for use in a light amplifier which can be used at wavelengths of both 1.3 μm and 1.55 μm.

Background Art

The wavelength of light used in optical communications has been shifted from a wavelength of 1.3 μm to a wavelength of 1.55 μm. In general, praseodymium ions (Pr^{+3}) which are used to dope an optical fiber, are used to amplify an optical signal having a wavelength of 1.3 μm while erbium ion (Er^{+3}) which are used to dope an optical fiber, are used to amplify an optical signal having a wavelength of 1.55 μm.

U.S. Patent No. 5,486,947 discloses an optical fiber for use in an optical amplifier, which are capable of operating with optical sufficient optical gain at the 1.3 μm wavelength. The optical fiber is a fluoride glass optical fiber containing rare earth metal ions in a core glass, wherein the refractive index difference between the core and a cladding layer is above 1.4%, and the glass contains lead difluoride (PbF_2) in a proportion of 25 mol % or less based on the total composition for forming the glass.

Now, both wavelengths of 1.3 μm and 1.55 μm are used in many optical communications related fields. Thus, different parts which are suitable for each wavelength, are required to construct an optical circuit, so that development cost increases in addition to switching cost for switching the wavelengths.

Disclosure of the Invention

An object of the present invention is to provide an optical fiber for use in an optical amplifier, which can be used for both the 1.3 μm and 1.55 μm bands.

According to an aspect of the present invention, there is provided an optical fiber for an optical amplifier, which is formed by doping glass with rare-earth ions, wherein both praseodymium ions (Pr^{+3}) and erbium ions (Er^{+3}) are used as the rare-earth ions, and the glass is a fluoride glass or a sulfide glass.

Preferably, the content of Pr^{+3} is 100~1000 ppm and the content of Er^{+3} is 100~5000 ppm. If the Pr^{+3} and Er^{+3} content is outside the above range, light amplification efficiency is undesirably lowered. Also, the mixing ratio of Pr^{+3} to Er^{+3}, by weight, may be between 1:1 and 1:3. If the ratio of Pr^{+3} to Er^{+3} exceeds the above ratio, fluorescence emission quantity at the wavelength of 1.55 μm is decreased. Conversely, if the ratio of Pr^{+3} to Er^{+3} is less than the above ratio, the amplification at the wavelength of 1.3 μm unfavorably decreased.

Brief Description of the Drawings

FIG. 1 shows the fluorescence emission spectrum at wavelengths of 1.3 μm and 1.55 μm according to the amount of Er^{+3} in optical fibers, when a laser beam having a wavelength of 980 nm is irradiated onto an optical fiber which is formed by doping glass made of $Ge_{29}As_8Ga_1S_{62}$ with Pr^{+3} and Er^{+3}, wherein the fluorescence emission at the wavelength of 1.3 μm is caused by the electron transition of Pr^{3+} from the $^1G_4$ level to the $^3H_5$ level in Pr^{+3} doped fibers, and that at the wavelength of 1.55 μm is caused by the transition $^4I_{13/2}$ - $^4I_{15/2}$ in Er^{3+} doped fibers ;

FIG. 2 is a graph showing the fluorescence lifetime of Pr^{+3} at the $^1G_4$ level and of Er^{+3} at the $^4I_{13}/2$ level and $^4I_{11}/2$ level according to the amount of Er^{+3} in optical fibers, when a laser beam having a wavelength of 980 nm is irradiated onto an optical fiber which is formed by doping a $Ge_{29}As_8Ga_1S_{62}$ glass with Pr^{+3} and Er^{+3};

FIG. 3 is a diagram illustrating energy transfer between Pr^{+3} and Er^{+3} ions;

FIG. 4 shows the fluorescence emission spectrum at the wavelength of 1.3 μm by the electron transition of Pr^{+3} from the $^1G_4$ level to the $^3H_5$ level when a laser beam having a wavelength of 1020 nm is irradiated onto an optical fiber which is formed by doping a $Ge_{29}As_8Ga_1S_{62}$ glass with Pr^{+3};

FIG. 5 shows the fluorescence emission spectrum at the wavelength of 1.55 μm by the electron transition of Er^{+3} from the $^4I_{13/2}$ level to the $^4I_{15/2}$ level when a laser beam having a wavelength of 980 nm is irradiated onto an optical fiber which is formed by doping a $Ge_{29}As_8Ga_1S_{62}$ glass with Er^{+3}; and

FIG. 6 shows the fluorescence emission spectrum at the wavelengths of 1.3 μm and 1.55 μm according to the amount of Pr^{+3} in optical fibers, when a laser beam having a wavelength of 980 nm is irradiated onto an optical fiber which is formed by doping a $Ge_{29}As_8Ga_1S_{62}$ glass with Pr^{+3} and Er^{+3}, wherein the fluorescence emission at the wavelength of 1.3 μm is due to the electron transition of Pr^{3+} from the $^1G_4$ level to the $^3H_5$ level, and that at the wavelength of 1.55 μm is due to the electron transition of Er^{3+} from the $^4I_{13/2}$ level to the $^4I_{15/2}$ level.

Best mode for carrying out the Invention

The present invention provides an optical fiber for use in a light amplifier, which can be used at wavelengths of both 1.3 μm and 1.55 μm, by using a laser beam having a wavelength of 980 nm as a light source for exciting an optical fiber formed of Pr^{+3} and Er^{+3}. In the present invention, the term "fibers" refers ro shapes with a wide range of diameters, not merely thin fibers. For example, a fiber may have diameter of 5 to 100mm. In the present invention, the fiber contains Pr^{+3} and Er^{+3}, wherein the maximum absorption peak of Er^{+3} in a laser beam having wavelength 980 nm is at the $^4I_{11/2}$ level. In this case, two ions are simultaneously excited, so that Pr^{+3} emits fluorescence at 1.3 μm and Er^{+3} emits fluorescence at 1.55 μm. In particular, as shown in FIG. 3, the fluorescence lifetime of Pr^{+3} at the $^1G_4$ level is elongated due to the energy transfer from Er^{+3}, so that light amplification efficiency is improved compared to a conventional optical fiber containing only Pr^{+3}.

Preferably, in the present invention, a fluoride or sulfide glass is used to minimize lattice vibration relaxation of Pr^{+3} from the $^1G_4$ level to $^3F_4$ level. The fluoride glass may be a ZBLAN glass which is a fluoride containing zirconium (Zr), barium (Ba), lanthanum (La), aluminum (Al) and sodium (Na), and the sulfide glass may be a germanium-arsenic-gallium-sulfur (Ge-As-Ga-

S) or Ge-As-S glass. Here, using the sulfide glass can further minimize the lattice vibration relaxation of Pr^{+3} from the $^1G_4$ level to the $^3F_4$ level compared to the case of using the fluoride glass. However, using the fluoride glass rather than a sulfide glass generally makes the manufacture of optical fiber easier.

In order to maximize the light amplification efficiency at both wavelengths of 1.3 μm and 1.55 μm, the mixing weight ratio of Pr^{+3} and Er^{+3} is adjusted to be between 1:1 and 1:3.

Hereinafter, the present invention will be described using the following examples. However, these examples are merely illustrative and the present invention is not limited thereto.

Comparative Example 1

Ge, As, Ga and S having a purity of 99.999% or more, were weighted in an atomic ratio of 29:8:1:62 in a glove box where the content of hydroxy (OH) group and oxygen was maintained to be 10 ppm or less, and Pr metal powder was added in amount of 300 ppm to give the Pr^{+3}.

After filling a SiO_2 test tube with the above composition, the test tube was left under a vacuum condition of 0.1 mTorr for a predetermined period of time. Then, the test tube was made airtight by sealing it with an oxy-propane flame.

Following this, the test tube was put into a rocking furnace such that the composition comprised in the test tube was completely mixed, and the resultant was kept at 950°C for 12 hours. Then, the test tube was quenched in air, and heated in a furnace which was set at 400°C for 1 hour. After the heating process, the test tube was slowly cooled to room temperature and broken into pieces, resulting in an optical fiber formed of a Pr^{+3}-doped sulfide glass of $Ge_{29}As_8Ga_1S_{62}$ in which the amount of lattice vibration relaxation was slight. The optical fiber was cut into a disc shape (having a diameter of 10 mm and a thickness of 3 mm) and polished.

Then, the fluorescence spectrum and fluorescence lifetime of the resultant were measured using a laser beam having a wavelength of 1017 nm as a source of light excitation. At this wavelength, Pr^{+3} at the $^1G_4$ level showed a maximum light absorption.

As a result, the fluorescence emission at a wavelength of 1.3 μm, which was caused by electron transition of Pr^{+3} from the $^1G_4$ level to $^3H_5$ level, was observed (see FIG. 4), and the fluorescence lifetime was 305 μsec (see FIG. 2).

Comparative Example 2

An optical fiber was manufactured in the same manner as in Comparative Example 1 except that Er^{+3} was used instead of Pr^{+3}. Er_2S_3 was used as the source of Er^{+3}. Then, the optical fiber was cut into a disc shape (having a diameter of 10 mm and a thickness of 3 mm) and polished. Then, the fluorescence spectrum and fluorescence lifetime of the resultant were measured using a laser beam having a wavelength of 980 nm as a source of light excitation. At this wavelength, Er^{+3} at the $^4I_{11/2}$ level showed a maximum light absorption.

As a result, the fluorescence emission at a wavelength of 1.55 μm, which was caused by electron transition of Er^{+3} from the $^4I_{13/2}$ level to $^4I_{15/2}$ level, was observed (see FIG. 5), and the fluorescence lifetime at the $^4I_{11/2}$ and $^4I_{13/2}$ levels was 2100 μsec and 3400 μsec, respectively (see FIG. 2)

Example 1

An optical fiber was manufactured in the same manner as in Comparative Example 1 except that Er^{+3} was further added in the amount of 300 ppm together with 300 ppm of Pr^{+3}. Then, the optical fiber was cut into a disc shape (having a diameter of 10 mm and a thickness of 3 mm) and polished. Then, the fluorescence spectrum and fluorescence lifetime of the resultant were measured using a laser beam having a wavelength of 980 nm as a source of light excitation. At this wavelength, Er^{+3} at the $^4I_{11/2}$ level showed a maximum light absorption.

As a result, the fluorescence emission of Pr^{+3}, which was caused by electron transition from $^1G_4$ level to $^3H_5$ level and that of Er^{+3}, which was caused by electron transition from $^4I_{13/2}$ level to $^4I_{15/2}$ level were observed simultaneously at the wavelengths of 1.3 μm and 1.55 μm, respectively (see

FIG. 1 (a)). The intensify of fluorescence was increased at each wavelength compared to that of Comparative Examples 1-2. Also, the fluorescence lifetime of Pr^{+3} at the $^{1}G_{4}$ level was 605 μsec, and the fluorescence lifetime of Er^{+3} at the $^{4}I_{11/2}$ and $^{4}I_{13/2}$ levels was 824 μsec and 3120 μsec, respectively (see FIG. 2).

According to Example 1, as shown in FIG. 3, the simultaneous fluorescence emission at the wavelengths of 1.3 μm and 1.55 μm was due to the effective energy transfer indicated by "b". Thus, the optical fiber obtained in Example 1 can be used at wavelengths of both 1.3 μm and 1.55 μm.

Also, the fluorescence lifetime of Pr^{+3} at the $^{1}G_{4}$ level was markedly elongated to 605 μsec compared to Comparative Example 1, and the light amplification efficiency at the wavelength of 1.3 μm was further improved by adding both Pr^{+3} and Er^{+3}. However, the fluorescence lifetime of Er^{+3} at the $^{4}I_{11/2}$ level was 3120 μsec, which is lower than in Comparative Example 2, thus lowering light amplification efficiency. This is due to the energy transfer indicated by "e".

Example 2

An optical fiber was manufactured in the same manner as in Comparative Example 1 except that 500 ppm of Er^{+3} was further added together with 300 ppm of Pr^{+3}. Then, the optical fiber was cut into a disc shape (having a diameter of 10 mm and a thickness of 3 mm) and polished. Then, the fluorescence spectrum and fluorescence lifetime of the resultant were measured using a laser beam having a wavelength of 980 nm as a source of light excitation. At this wavelength, Er^{+3} at the $^{4}I_{11/2}$ level showed a maximum light absorption.

As a result, the fluorescence emission of Pr^{+3}, which was caused by electron transition from $^{1}G_{4}$ level to $^{3}H_{5}$ level and that of Er^{+3}, which was caused by electron transition from $^{4}I_{13/2}$ level to $^{4}I_{15/2}$ level were observed simultaneously at the wavelengths of 1.3 μm and 1.55 μm, respectively (see FIG. 1 (b)). The intensify of fluorescence was increased at each wavelength

compared to that of the Comparative Examples 1-2. Also, the fluorescence lifetime of Pr^{+3} at the $^1G_4$ level was 760 μsec, and the fluorescent lifetime of Er^{+3} at the $^4I_{11/2}$ and $^4I_{13/2}$ levels was 1740 μsec and 2910 μsec, respectively (see FIG. 2).

According to Example 2, as shown in FIG. 3, the simultaneous fluorescence emission at the wavelengths of 1.3 μm and 1.55 μm was due to the effective energy transfer indicated by "b". Also, the fluorescence lifetime of Pr^{+3} at the $^1G_4$ level was markedly elongated to 760 μsec compared to Comparative Example 1 and Example 1, and the fluorescence lifetime of Er^{+3} at the $^4I_{13/2}$ level was decreased to 2910 μsec, compared to Comparative Example 2 and Example 1.

From the above result, it can be understood that the energy transfer indicated by "b" and "e" occur more effectively as the content of Er^{+3} increases. However, the fluorescence lifetime of Er^{+3} at the $^4I_{11/2}$ level was increased to 1740 μsec, compared to Example 1. As a result, it was concluded that as Er^{+3}, which is not involved in the energy transfer indicated by "b", increases, the energy transfer degree in the direction indicated by "b" decreases.

Example 3

An optical fiber was manufactured in the same manner as in Comparative Example 1 except that 700 ppm of Er^{+3} was further added together with 300 ppm of Pr^{+3}. Then, the optical fiber was cut into a disc shape (having a diameter of 10 mm and a thickness of 3 mm) and polished. Then, the fluorescence spectrum and fluorescence lifetime of the resultant were measured using a laser beam having a wavelength of 980 nm as a source of light excitation. At this wavelength, Er^{+3} at the $^4I_{11/2}$ level showed a maximum light absorption.

As a result, the fluorescence emission of Pr^{+3}, which was caused by electron transition from $^1G_4$ level to $^3H_5$ level and that of Er^{+3}, which was caused by electron transition from $^4I_{13/2}$ level to $^4I_{15/2}$ level were observed simultaneously at the wavelengths of 1.3 μm and 1.55 μm, respectively (see

FIG. 1 (c)). The intensify of fluorescence was increased at each wavelength compared to that of Examples 1-2. Also, the fluorescence lifetime of Pr^{+3} at the $^1G_4$ level was 769 μsec, and the fluorescence lifetime of Er^{+3} at the $^4I_{11/2}$ and $^4I_{13/2}$ levels was 1760 μsec and 2920 μsec, respectively (see FIG. 2).

According to Example 3, as the content of Er^{+3} increased, the fluorescence lifetime of Pr^{+3} at the $^1G_4$ level was slightly increased. This was due to an increase in energy transfer indicated by "b" shown in FIG. 3. However, because Er^{3+} was contributed for elongating the fluorescence lifetime at the $^4I_{11/2}$ and $^4I_{13/2}$ levels, the ratio of Er^{+3} associated with the energy transfer indicated by "b" and "e" was decreased, thus resulting in a slight increase in fluorescence lifetime of Pr^{+3} at the $^1G_4$ level. That is, the light amplification efficiency at the wavelength of 1.55 μm showed a tendency to increases with an increase in the fluorescence lifetime of Er^{+3} at the $^4I_{13/2}$ level.

Example 4

An optical fiber was manufactured in the same manner as in Comparative Example 1 except that 1000 ppm of Er^{+3} was further added together with 300 ppm of Pr^{+3}. Then, the optical fiber was cut into a disc shape (having a diameter of 10 mm and a thickness of 3 mm) and polished. Then, the fluorescence spectrum and fluorescence lifetime of the resultant were measured using a laser beam having a wavelength of 980 nm as a source of light excitation. At this wavelength, Er^{+3} at the $^4I_{11/2}$ level showed a maximum light absorption.

As a result, the fluorescence emission of Pr^{+3}, which was caused by electron transition from $^1G_4$ level to $^3H_5$ level and that of Er^{+3}, which was caused by electron transition from $^4I_{13/2}$ level to $^4I_{15/2}$ level were observed simultaneously at the wavelengths of 1.3 μm and 1.55 μm, respectively (see FIG. 1 (d)). The intensify of fluorescence was increased at each wavelength compared to that of Examples 1-3. Also, the fluorescence lifetime of Pr^{+3} at the $^1G_4$ level was 881 μsec, and the fluorescent lifetime of Er^{+3} at the $^4I_{11/2}$ and $^4I_{13/2}$ levels was 2030 μsec and 3340 μsec, respectively (see FIG. 2).

According to Example 4, as shown in FIG. 3, the simultaneous fluorescence emission at the wavelength of 1.3 μm by Pr^{+3} at the $^1G_4$ level, and at the wavelength of 1.55 μm by Er^{+3} at the $^4I_{13/2}$ level, was due to effective energy transfer indicated by "b". Also, the fluorescence lifetime of Er^{+3} at the $^4I_{11/2}$ and $^4I_{13/2}$ levels showed the maximum levels. Thus, it can be understood that the mixing ratio of Pr^{+3} and Er^{3} in this embodiment shows the maximum light amplification efficiency at both 1.3 μm and 1.55 μm.

Example 5

An optical fiber was manufactured by the same manner as in Comparative Example 1 except that 1500 ppm of Er^{+3} was further added together with 300 ppm of Pr^{+3}. Then, the optical fiber was cut into a disc shape (having a diameter of 10 mm and a thickness of 3 mm) and polished. Then, the fluorescence spectrum and fluorescence lifetime of the resultant were measured using a laser beam having a wavelength of 980 nm as a source of light excitation. At this wavelength, Er^{+3} at the $^4I_{11/2}$ level showed a maximum light absorption.

As a result, the fluorescence emission of Pr^{+3}, which was caused by electron transition from $^1G_4$ level to $^3H_5$ level and that of Er^{+3}, which was caused by electron transition from $^4I_{13/2}$ level to $^4I_{15/2}$ level were observed simultaneously at the wavelengths of 1.3 μm and 1.55 μm, respectively (see FIG. 1 (e)). The intensify of fluorescence was saturated, i.e., at the maximum level, at each wavelength. Also, the fluorescence lifetime of Pr^{+3} at the $^1G_4$ level was 794 μsec, and the fluorescence lifetime of Er^{+3} at the $^4I_{11/2}$ and $^4I_{13/2}$ levels was 1870 μsec and 3240 μsec, respectively (see FIG. 2).

According to Example 5, as shown in FIG. 3, the simultaneous fluorescence emission at the wavelength of 1.3 μm by Pr^{+3} at the $^1G_4$ level and at the wavelength of 1.55 μm by Er^{+3} at the $^4I_{13/2}$ level was due to effective energy transfer indicated by "b". The fluorescence lifetime of Er^{+3} at the $^4I_{11/2}$ and $^4I_{13/2}$ levels was slightly decreased compared to Example 4, because the energy transfer indicated by "b" and "e" were saturated.

Example 6

Ge, Ga and S having a purity of 99.999% or more, were weighted in an atomic ratio of 25:5:70 in a glove box where the content of hydroxy (OH) group and oxygen was maintained to be 10 ppm or less, and 300 ppm of Pr^{+3} and 300 ppm of Er^{+3} were added.

After filling a SiO_2 test tube with the composition, the test tube was left under a vacuum condition of 0.1 mTorr for a predetermined period of time. Then, the test tube was made airtight by sealing it with an oxy-propane flame.

Following this, the test tube was put into a rocking furnace such that the composition comprised in the test tube was completely mixed, and the resultant was kept at 950°C for 12 hours. Then, the test tube was quenched in air, and heated in a furnace which was set at 260°C for 1 hour. After the heating process, the test tube was slowly cooled to room temperature and broken into pieces, resulting in an optical fiber formed of a Pr^{+3} and Er^{+3} doped sulfide glass of $Ge_{25}Ga_5S_{70}$ in which the amount of lattice vibration relaxation was slight.

The optical fiber was cut into a disc shape (having a diameter of 10 mm and a thickness of 3 mm) and polished. Then, the fluorescence spectrum and fluorescence lifetime of the resultant were measured using a laser beam having a wavelength of 980 nm as a source of light excitation. At this wavelength, Er^{+3} at the $^4I_{11/2}$ level showed a maximum light absorption.

As a result, the fluorescence emission of Pr^{+3}, which was caused by electron transition from $^1G_4$ level to $^3H_5$ level and that of Er^{+3}, which was caused by electron transition from $^4I_{13/2}$ level to $^4I_{15/2}$ level were observed simultaneously at the wavelengths of 1.3 μm and 1.55 μm, respectively (see FIG. 6 (a)).

According to Example 6, it can be understood that both a Ge-GA-S glass doped with Pr^{+3} and Er^{+3} and a Ge-As-Ga-S glass doped with Pr^{+3} and Er^{+3} can be used as a material of an optical amplifier which can be used at both 1.3 μm and 1.55 μm.

Example 7

An optical fiber was manufactured in the same manner as in Example 6 except that the amount of Pr^{+3} was increased to 500 ppm. Then, the optical fiber was cut into a disc shape (having a diameter of 10 mm and a thickness of 3 mm) and polished. Then, the fluorescence spectrum and fluorescence lifetime of the resultant were measured using a laser beam having a wavelength of 980 nm as a source of light excitation. At this wavelength, Er^{+3} at the $^4I_{11/2}$ level showed a maximum light absorption.

As a result, the fluorescence emission of Pr^{+3}, which was caused by electron transition from $^1G_4$ level to $^3H_5$ level and that of Er^{+3}, which was caused by electron transition from $^4I_{13/2}$ level to $^4I_{15/2}$ level were observed simultaneously at the wavelengths of 1.3 μm and 1.55 μm, respectively (see FIG. 6 (b)). Also, as the amount of Pr^{+3} was increased, energy transfer in directions indicated by "b" and "e" in FIG. 3 increased. As a result, the fluorescence intensity of Pr^{+3} at the $^1G_4$ level increased at the wavelength of 1.3 μm, whereas that of Er^{+3} at the $^4I_{13/2}$ level decreased at the wavelength of 1.55 μm. However, the rate at which the fluorescence intensity increases at 1.3 μm is slower than the rate at which the fluorescence intensity decreases at 1.55 μm, and thus it can be inferred that the energy transfer indicated by "e" is more rapid than that indicated by "b".

Summing up the results, it can be understood that increasing the concentration of Pr^{+3} is undesirable.

Industrial Applicability

As described above, the optical fiber used in an optical amplifier according to the present invention can be applied to both wavelengths of 1.3 μm and 1.55 μm, improving light amplification efficiency compared to a conventional optical fiber amplifier containing only Pr^{+3}.

<u>What is claimed is:</u>

1. An optical fiber for an optical amplifier, which is formed by doping glass with rare-earth ions, wherein both praseodymium ions (Pr^{+3}) and erbium ions (Er^{+3}) are used as the rare-earth ions, and the glass is a fluoride glass or a sulfide glass.

2. The optical fiber of claim 1, wherein the sulfide glass is a germanium-arsenic-gallium-sulfide (Ge-As-Ga-S) glass or a Ge-As-S glass.

3. The optical fiber of claim 1, wherein the fluoride glass is a ZBLAN glass containing zirconium (Zr), barium (Ba), lanthanum (La), aluminum (Al) and sodium (Na).

4. The optical fiber of claim 1, wherein the mixing weight ratio of Pr^{+3} to Er^{+3} is between 1:1 and 1:3.

5. The optical fiber of claim 1, wherein a laser having a wavelength capable of absorbing Er^{+3} is used as a light source for exciting the optical fiber.

6. The optical fiber of claim 1, wherein the content of Pr^{+3} is 100~1000 ppm and the content of Er^{+3} is 100~5000 ppm.

FIG. 1

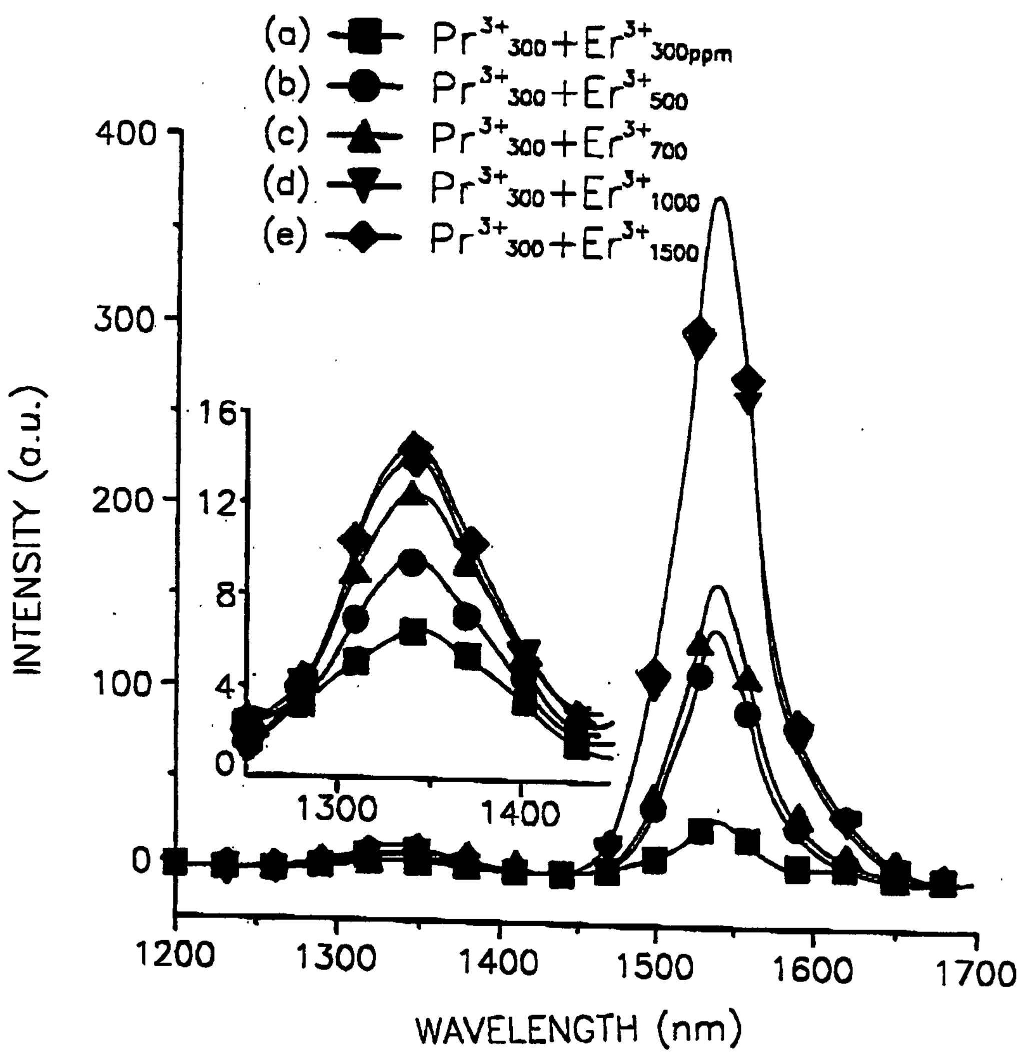

(a) Pr3+300+Er3+300ppm
(b) Pr3+300+Er3+500
(c) Pr3+300+Er3+700
(d) Pr3+300+Er3+1000
(e) Pr3+300+Er3+1500
400
300
200
100
0
INTENSITY (a.u.)
16
12
8
4
0
1300
1400
1200
1300
1400
1500
1600
1700
WAVELENGTH (nm)

FIG. 2

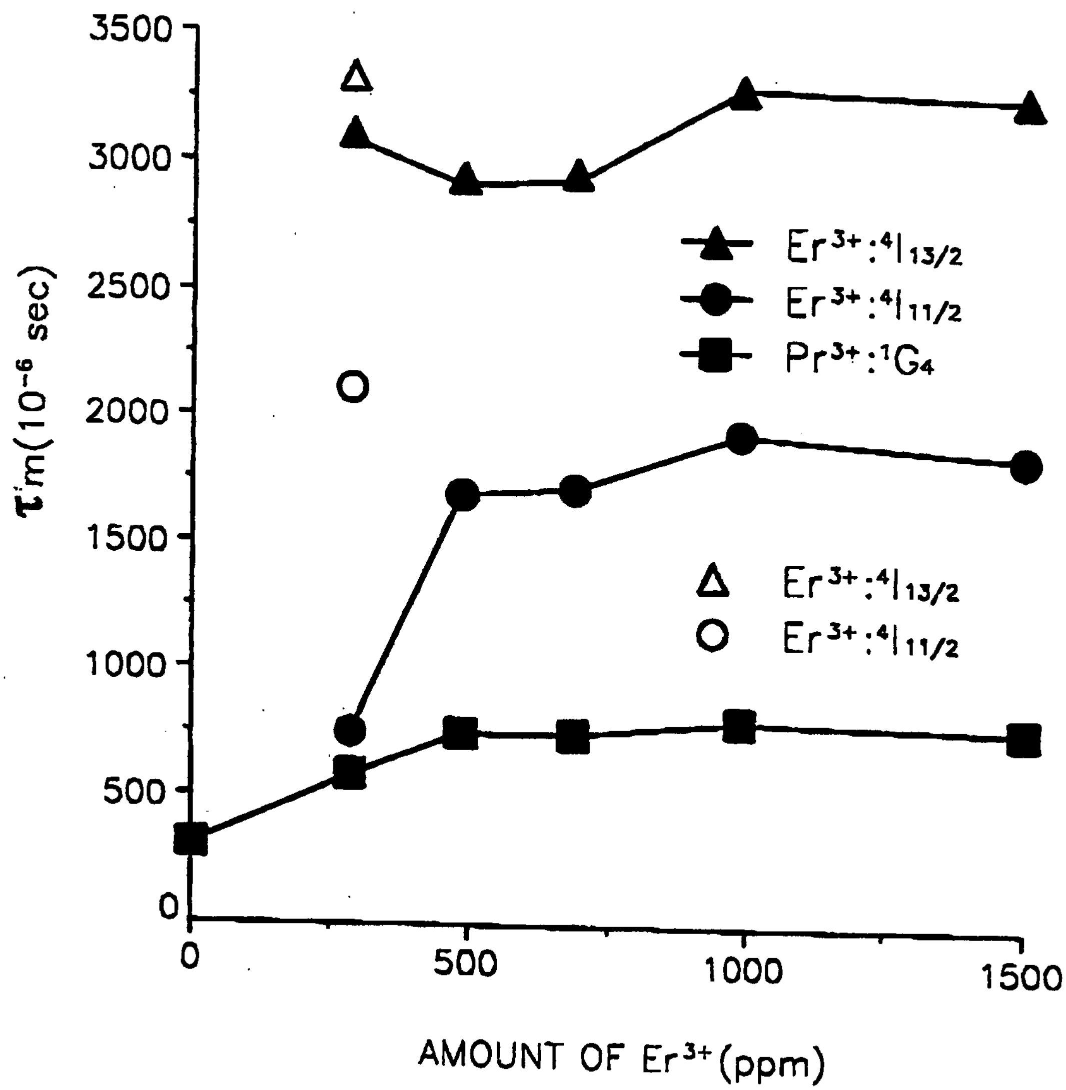
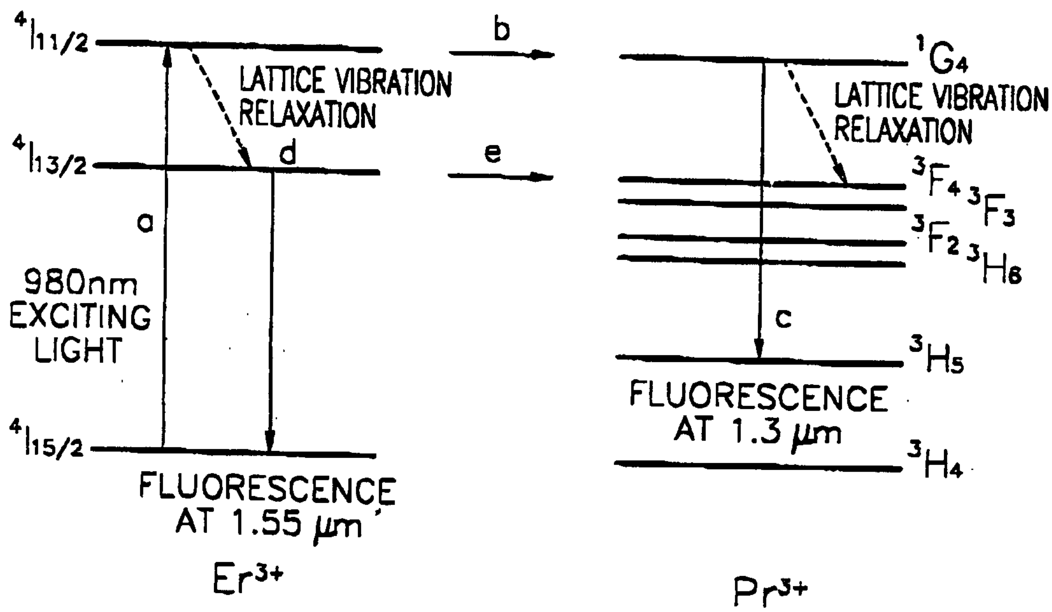
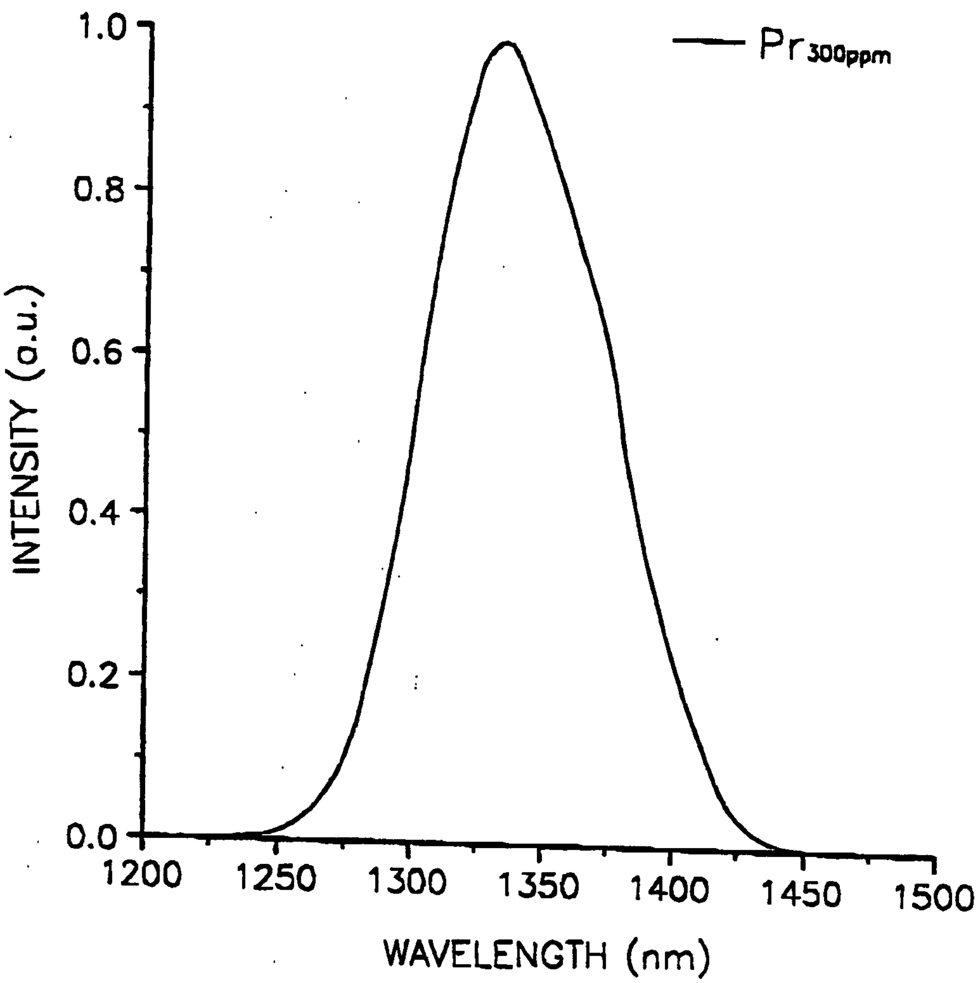

3500
3000
2500
2000
1500
1000
500
0
τ_m (10^{-6} sec)
0
500
1000
1500
AMOUNT OF Er^{3+} (ppm)
Er^{3+} : $^4I_{13/2}$
Er^{3+} : $^4I_{11/2}$
Pr^{3+} : $^1G_4$
Er^{3+} : $^4I_{13/2}$
Er^{3+} : $^4I_{11/2}$

FIG. 3



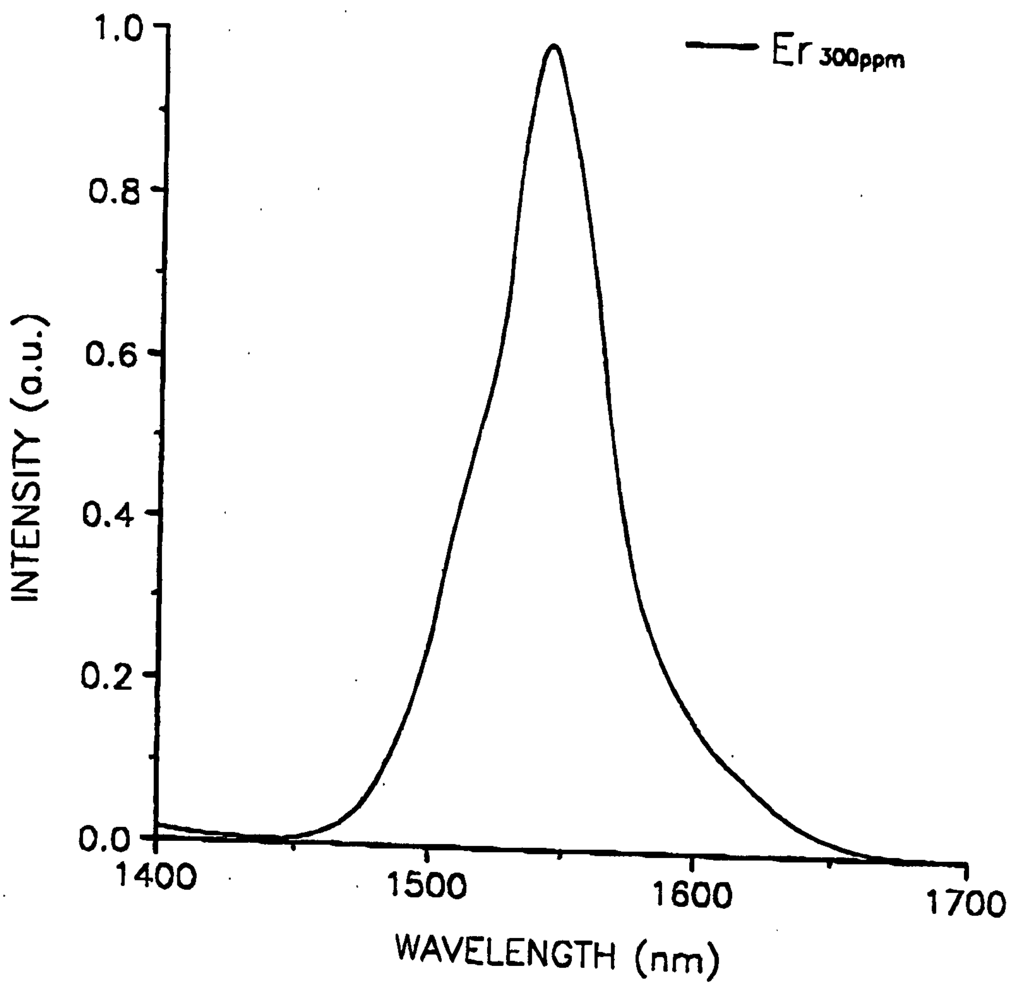
$^4I_{11/2}$
LATTICE VIBRATION RELAXATION
$^4I_{13/2}$
d
a
980nm EXCITING LIGHT
$^4I_{15/2}$
FLUORESCENCE AT 1.55 μm
Er^{3+}
b
e
$^1G_4$
LATTICE VIBRATION RELAXATION
$^3F_4$
$^3F_3$
$^3F_2$
$^3H_6$
c
$^3H_5$
FLUORESCENCE AT 1.3 μm
$^3H_4$
Pr^{3+}

FIG. 4



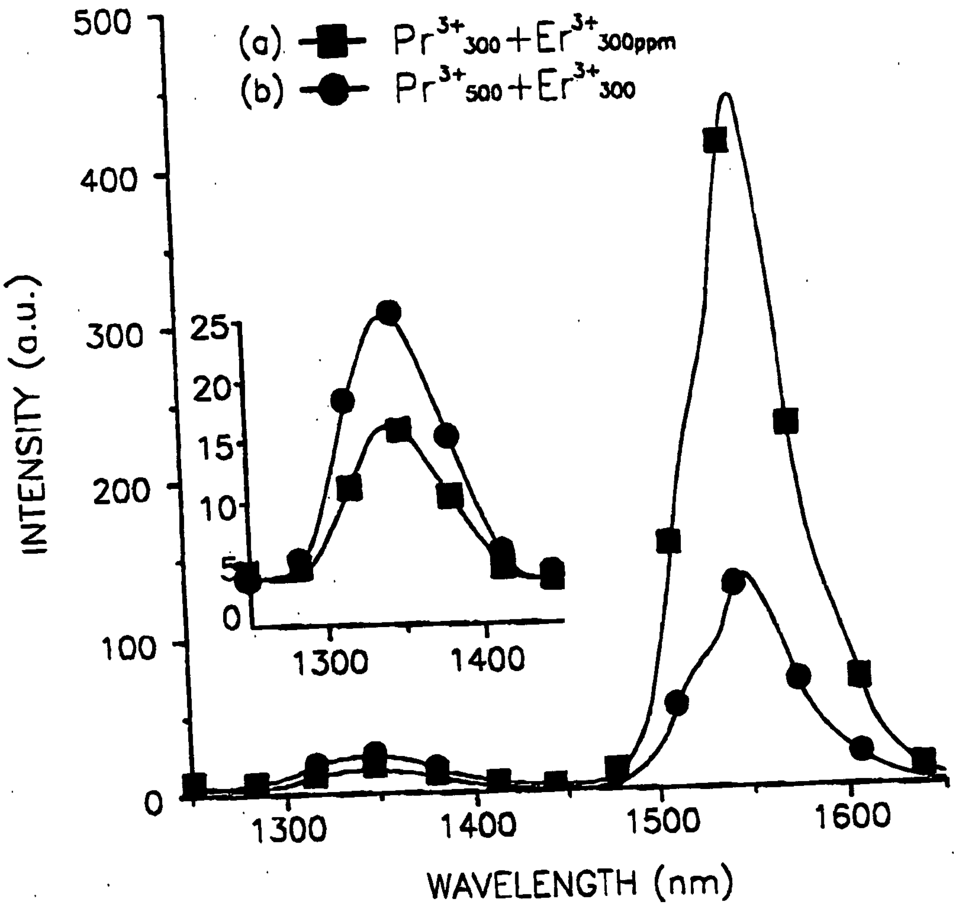
1.0
0.8
0.6
0.4
0.2
0.0
INTENSITY (a.u.)
Pr300ppm
1200
1250
1300
1350
1400
1450
1500
WAVELENGTH (nm)

FIG. 5



Er 300ppm
1.0
0.8
0.6
0.4
0.2
0.0
INTENSITY (a.u.)
1400
1500
1600
1700
WAVELENGTH (nm)

FIG. 6



(a) Pr3+300+Er3+300ppm
(b) Pr3+500+Er3+300
INTENSITY (a.u.)
WAVELENGTH (nm)
500
400
300
200
100
0
1300
1400
1500
1600
25
20
15
10
5
0
1300
1400

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR 99/00609

A. CLASSIFICATION OF SUBJECT MATTER

IPC[7]: C 03 C 13/04; H 01 S 3/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC[7]: C 03 C; H 01 S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, EPODOC, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5486947 A (OHISHI et al.), 23 January 1996 (23.01.96), abstract; column 2, line 45 - column 3, line 58; example 29.	1,3-6
A	EP 0511069 A1 (ALCATEL N.V.), 28 October 1992 (28.10.92), claim 1; column 2, lines 1-9.	1,3
A	JP 08-104533 A (NIPPON TELEGRAPH), 23 April 1996 (23.04.96), (abstract), [online] [retrieved on 24 November 1999 (24.11.99)]. Retrieved from: EPO PAJ Database.	1

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
„A" document defining the general state of the art which is not considered to be of particular relevance
„E" earlier application or patent but published on or after the international filing date
„L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
„O" document referring to an oral disclosure, use, exhibition or other means
„P" document published prior to the international filing date but later than the priority date claimed

„T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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„Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
„&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 November 1999 (24.11.99)	18 February 2000 (18.02.00)
Name and mailing adress of the ISA/AT Austrian Patent Office Kohlmarkt 8-10; A-1014 Vienna Facsimile No. 1/53424/200	Authorized officer Hauswirth Telephone No. 1/53424/136

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/KR 99/00609

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